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# Use of Natural Ventilation to Control Radon in Single Family Dwellings

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16. ABSTRACT The paper discusses an examination of a fundamental assumption in radon mitigation work, that natural ventilation is not very effective in lowering indoor radon levels in buildings. (The mechanism by which ventilation acted to reduce radon levels was considered to be simple dilution; thus a factor of 10 increase in the air exchange rate would be required to reduce radon levels by this same factor.) The examination (in a natural ventilation experiment in a research house)showed that this assumption is fundamentally incorrect. Measuring the pressure field of a basement in conjunction with the building air exchange rate shows that ventilation reduces radon levels two ways: (1) by dilution, and (2) by modification of the pressure field of the building shell. The experiment indicates that effect (2) is much more important than (1)--dilution--and that natural ventilation can cause a much larger reduction in radon levels than was previously believed possible.

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# USE OF NATURAL VENTILATION TO CONTROL RADON IN SINGLE FAMILY DWELLINGS

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## Abstract

A fundamental assumption in radon mitigation work has been that natural ventilation was not a very effective means of lowering indoor radon levels in buildings. The mechanism by which ventilation acted to reduce radon levels was considered to be simple dilution. Thus, a factor of ten increase in the air exchange rate would be required to reduce radon levels by this same factor. This assumption has been examined and found to be fundamentally incorrect in a natural ventilation experiment in a research house. Measurement of the pressure field of a basement in conjunction with the building air exchange rate shows that ventilation reduces radon levels in two ways. The first is by dilution, the second is by modification of the pressure field of the building shell. This experiment indicates that the second effect is much more important than the first (dilution), and that natural ventilation can cause a much larger reduction in radon levels than was previously believed.

## INTRODUCTION

An attractive candidate for a radon mitigation system in some areas of the United States is one which uses natural basement ventilation to reduce indoor radon levels. Such a system would be simple to install, inexpensive to operate, and virtually maintenance free. It is very important to determine how effective such a system would be in an actual operating household throughout the year, and whether its impact on heating and air conditioning costs and basement humidity levels outweighs its obvious advantages.

Radon entry into a structure is dominated by pressure-driven flows of soil gas into the building. The pressure field of the building results from the following effects: wind generated pressure differentials, building depressurization caused by the operation of heating or cooling systems, and most importantly, pressure differences created by the temperature difference between the outside environment and the building interior.

Results from earlier ventilation experiments (1,2,3) led to the conclusion that ventilation was not a reasonable method to reduce indoor radon levels. The physical mechanism by which radon levels were lowered was found to be simple dilution: that is, indoor radon concentration was inversely proportional to the air exchange rate. Thus, a factor of ten increase in the air exchange rate would be necessary to reduce radon levels by the same factor. In most cases this is neither practical nor desirable. This result was obtained using a mechanical air to air heat exchanger to control the ventilation rate in a basement. This is very different from a natural ventilation experiment in which a basement window is opened. Nonetheless it resulted in ventilation being thoroughly discredited as a means to control indoor radon.

This view of ventilation is based on a standard model. If the radon source terms are equated to the radon sink terms of radioactive decay and removal by ventilation, we have:

$$S_r = \lambda_v C_o + \lambda_o C_o.$$

Here $S_r$ is the radon entry rate, $\lambda_v$ is the air exchange rate, $C_o$ is the radon concentration, and $\lambda_o$ is the radioactive decay constant of radon. Thus, for a source rate resulting in a radon concentration of 700 Bq/m$^3$, a factor of ten increase in the ventilation rate would be necessary to reduce the radon level to 70 Bq/m$^3$. This would be an unacceptably high air exchange rate.

The hidden assumption is that the radon entry rate $S_r$ is a constant. This is not the case at all: $S_r$ can be changed by a large factor by ventilation. The pressure field which drives radon gas into the basement of a dwelling as well as the ventilation rate are affected by opening a basement window.

## EXPERIMENT

The conclusions of these original ventilation experiments have been reexamined and found to be fundamentally inadequate in natural ventilation experiments on a Princeton University research house.

The research house has the following characteristics:

| | |
|---|---|
| SIZE: | 150 m$^2$ (1600 sq ft) living area, 120 m$^2$ (1300 sq ft) basement |
| TYPE: | Ranch with full attic and full basement, half of an attached two car garage converted to TV room, cinderblock wall basement, cinderblock chimney stack in the center of the house, and the basement has a sump pump |
| ATTIC: | Two 0.52 m$^3$/s (1100 cfm) attic fans (thermostatically controlled) and insulated with 20 cm (8 in) of blown-in insulation |
| FIREPLACES: | Two: one in living room, and one in kitchen |
| HEATING SYSTEM: | Central gas forced air heat, furnace located in basement |
| COOLING SYSTEM: | Central air conditioning |
| HOT WATER: | Gas hot water heater located in basement |
| RADON LEVEL: | ~3000 Bq/m$^3$ in the basement. |

The research house has been instrumented as follows:

1. The pressure field of the basement is measured at three heights on each basement wall and at three subslab locations with variable capacitance differential pressure transducers manufactured by Setra Systems, Inc. [model 261-1, range = +/-62 Pa]
2. Thermocouples measure basement and outdoor temperatures.
3. Radon levels are measured using a CRM (continuous radon monitor from Lawrence Berkeley Laboratory) or a Pylon radon monitor.
4. Basement relative humidity is measured using a Campbell Scientific 207 relative humidity probe.
5. A PFT (perfluorocarbon tracer) system is used to measure the air infiltration rate and interzonal flows. Eight emitters in four temperature regulated holders and four emitters in as many regulated holders are located in the basement and the living area, respectively. Six CATs (capillary adsorption tubes) are located in the living area and six in the basement

to sample different locations in each zone and verify that the volumes are well mixed.
6. Heating and air conditioning (HAC) utilization is monitored with a sail switch.

In addition, a weather station at Princeton University, 11.3 km (7 mi) east of the test house, monitors temperature, rainfall, relative humidity, wind speed and direction.

The natural ventilation experiment was conducted in the following manner. A 17 day period was used to establish an operating baseline for the house. During this time the house functioned normally; e.g., thermostatically controlled attic fans operated automatically. Basement and upstairs windows were kept closed, as is normally the case since the house is centrally air conditioned. (Upstairs windows were of excellent quality and could be closed tightly. The basement windows were low quality steel frame casements which could not be shut very tightly.)

After the baseline operating conditions of the building were established, two basement windows (one on the west wall and the other on the east wall, each each 0.2 $m^2$ (2.2 sq ft) were opened and the relevant parameters compared to those obtained in the baseline conditions.

## RESULTS

The effect of opening two basement windows on basement radon levels and the soil to basement pressure differential is shown in Figures 1a and b. Basement radon levels are shown in Figure 1a; there is clearly a significant drop in this parameter, from an average of about 3330 $Bq/m^3$ to about 370 $Bq/m^3$ when the windows are opened on day 8.6. The magnitude of this drop was completely unexpected. The large diurnal variation in basement radon levels is due to the operation of the attic fans which depressurize the entire house, increasing the ventilation rate as well as the radon levels. Measurements of a typical differential pressure transducer are illustrated in Figure 1b (positive pressure indicates the soil pressure is above that of the basement). The large peaks (~2 Pa) in soil-basement pressure differentials are due to the operation of the attic fans. There is an abrupt pressure drop when the windows are opened, indicating that the pressure field of the building has been modified. It is clear that for this house only a very small pressure differential (~0.2 Pa) is needed to drive the radon level to 300 $Bq/m^3$. This result is extremely suggestive; however, the measurement of ventilation rates is essential for a definitive evaluation of these data.

The behavior of the building and basement air exchange rates is shown in Figure 2; these two parameters are plotted for seven experiments, each of 3-4 days duration. This period of time was needed to obtain reasonable levels of the perfluorocarbon tracer gas in the capillary adsorption tubes. Baseline conditions for the building (with the attic fans thermostatically controlled) were about 0.3 ACH (air changes/hour) for the entire building, 0.9 ACH for the basement, and average basement radon levels of about 3000 $Bq/m^3$.

With the basement windows opened, the building air exchange rate increases by about a factor of two, to 0.6 ACH, and the basement air exchange rate increases by about 30%, to 1.2 ACH. (Note that the uncertainty in the latter measurement is about 40%.) Basement radon levels decrease to about 440 $Bq/m^3$, a factor of about 7.5 below the levels with the windows closed. This decrease is far larger than the increase in the building air exchange rate (about a factor of two), and indicates that the change in the pressure field of the

building is much more important in decreasing radon levels than the increase in the building air exchange rate.

To investigate the impact of the attic fans on building operation the two basement windows were left open and the attic fans switched off. Both building and basement air exchange rates dropped by about a factor of two in this case, while the basement radon level dropped by about 20%. Such a large decrease in the air exchange rate without any increase in radon levels is yet another indication that the modification of the pressure field of the basement and thus the source rate $S_r$ (which is a function of the soil to basement pressure differential) is of prime importance in determining the radon level of this basement.

Although basement radon levels have been emphasized in the above analysis, radon levels in the living area are of most concern. These have also been measured during the natural ventilation experiments. With all windows closed, the upstairs radon level (~2300 $Bq/m^3$) was lower than the basement radon level (~3000 $Bq/m^3$), as would be expected. However, with basement windows opened, the upstairs radon level (~985 $Bq/m^3$) was about 2.5 times higher than the basement radon level (~370 $Bq/m^3$). Instrument error has been carefully ruled out in this case. It is clear that radon can enter the upstairs zone of this house two different ways. The first is the usual one in which soil gas is drawn into the basement and then flows into the upstairs zone. The second entry route could not be localized, but may be associated with the central cinderblock chimney stack or the slab on grade garage which has been converted into a TV room. This second route is unaffected by the pressure break and the ventilation provided by the open basement windows.

## CONCLUSIONS

A natural ventilation experiment conducted in a research house has shown that basement ventilation decreases basement radon levels predominantly by decreasing the soil to basement pressure differential which in turn lowers the radon entry rate into the basement. Dilution of the radon by an increase in the air exchange rate is a secondary effect. However, basement ventilation cannot be applied indiscriminately as a radon reduction method since this experiment has also shown that there may be radon entry routes into the living area other than the usual one through the basement. Careful measurements are needed to verify that radon in both the living area and the basement reduced significantly with this technique.

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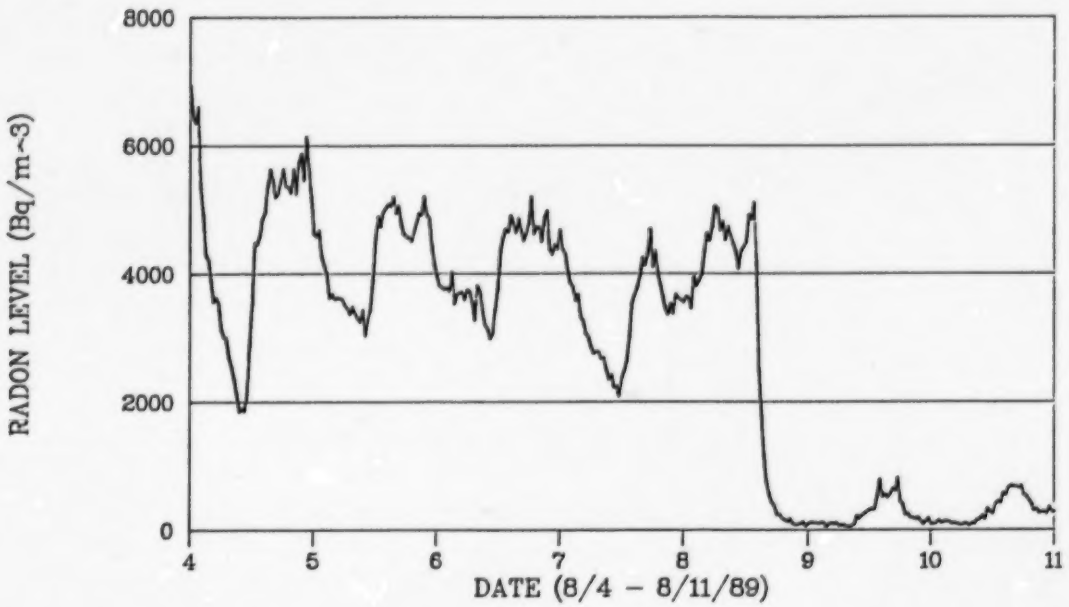


FIGURE 1a. Basement radon levels ($Bq/m^3$) vs. time (days). Two basement windows are opened at day 8.6.

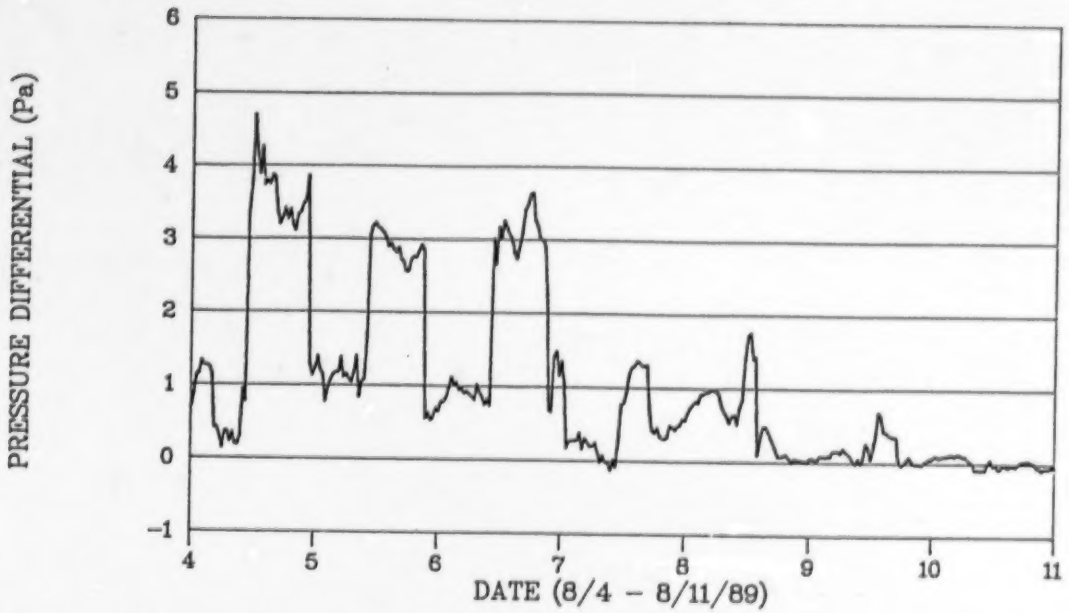


FIGURE 1b. Soil to basement pressure differential (Pa) vs. time (days). Two basement windows are opened at day 8.6.

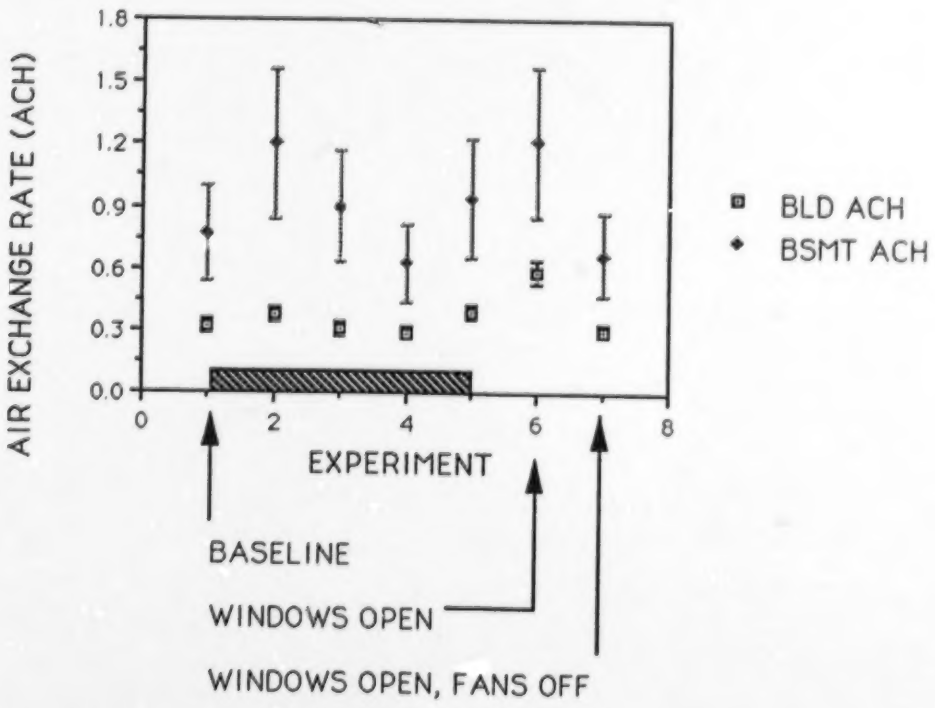


FIGURE 2. Building and basement air exchange rate (ACH) for seven experiments, each of 3-4 days duration. The first five establish the house baseline operating conditions, the sixth is with the basement windows open and the seventh is with windows open but attic fans switched off.